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THE EFFECT OF THE TIME RESTRICTIONS ON INFORMATION SEARCH AND INFORMATION INTEGRATION IN A DYNAMIC TASK ENVIRONMENT

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SUMMARY

To date, research has mainly used deadlines in static task environments to investigate the effects of time pressure on decision making behaviour. A dynamic environment, on the other hand, changes over time and time pressure may result when time is not used efficiently and negative consequences are rapidly increasing.

An experiment was carried out to investigate the effects of time horizon on decision making behaviour in a dynamic task environment. Subjects were required to monitor the fitness level of a running athlete, depicted graphically on a computer screen, and to apply a proper treatment whenever necessary. Information could be requested on symptoms, which were probabilistically related to underlying causes. The time horizon was manipulated by the speed at which the athlete's fitness level changed over time.

Restrictions in time horizon did not affect the amount and type of information that was requested, and the diagnoses became even better. Nevertheless, more athletes collapsed in the more restricted time horizon conditions. In the short time horizon conditions subjects furthermore employed a more cautious decision strategy. As far as the use of time was concerned it was found that information processing was speeded up, but subjects waited relatively the same amount of time before they started to intervene with the system.

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Het effect van tijdsbeperkingen op het zoeken en integreren van informatie in een dynamische taakomgeving

J.H. Kerstholt en P. Willems

SAMENVATTING

Tot op heden zijn voornamelijk deadlines in statische taken gebruikt om het effect na te gaan van tijdsdruk op beslisgedrag. Dynamische omgevingen, daarentegen, veranderen over tijd en tijdsdruk kan ontstaan als de tijd niet goed wordt gebruikt en de kans op negatieve gevolgen snel toeneemt.
Een experiment werd uitgevoerd om het effect na te gaan van tijdhorizon op het beslisgedrag in een dynamische taakomgeving. De proefpersonen moesten het conditieniveau van een atleet in de gaten houden, dat werd afgebeeld met behulp van een grafiek op een computerscherm, en indien nodig moesten zij de atleet ook "behandelen". Informatie over symptomen kon worden opgevraagd, die probabilistisch was gerelateerd aan mogelijke oorzaken van een verslechtering van het conditieniveau. De *tijdhorizon* werd gemanipuleerd door de snelheid waarmee het conditieniveau van de atleet veranderde over tijd.
Beperkingen in tijdhorizon beïnvloedde niet de hoeveelheid en de soort informatie die werd opgevraagd, en de diagnoses werden zelfs beter. Meer atleten liepen echter "stuk" met een beperkte tijdhorizon. Met een korte tijdhorizon werd een voorzichtiger strategie gehanteerd. Men verwerkte de informatie sneller als de tijdhorizon korter was maar de proefpersonen wachtten tot eenzelfde conditieniveau voordat zij begonnen met het opvragen van informatie.

1 INTRODUCTION

Even though time has to be taken into consideration in many decision making situations (for example, patient care, operating process plants or car driving), only a few studies have investigated the time-dimension of decision making strategies. To date, research has mostly been concerned with decision making behaviour in static task environments, in which the decision making context does not change over time. Time becomes relevant in such environments when deadlines are imposed on subjects, which plausibly cause them to process the relevant information only to some degree. Maule and Mackie (1990) divide research on the effects of deadlines on decision making behaviour according to two basic approaches. The first approach investigates the effects of time pressure at a macro-level, and registers decision strategies by, for example, using information boards (Ford et al., 1989). A major conclusion from these studies is that people switch from compensatory strategies to noncompensatory strategies under the more restricted deadlines (Payne, Bettman & Johnson, 1988; Zakay, 1985). On using noncompensatory strategies, alternatives are accepted or rejected by the evaluation of single attribute values, rather than by an overall evaluation that underlies the compensatory strategies (Billings & Marcus, 1983).
The second approach investigates the effects of deadlines on decision making behaviour at a micro-level and is more concerned with the adaptive, cognitive mechanisms to cope with information overload. In this line of research it has been found that deadlines induce subjects to increase processing speed, which occurs to a greater extent in combining information than in searching information, to place more weight on negative information and to take fewer risks (Ben Zur & Breznitz, 1981; Maule & Mackie, 1990; Payne, Bettman & Johnson, 1988; Wright, 1974). Payne, Bettman and Johnson (1990) suggested a hierarchy of adaptive responses to deadlines: first people may try to do the same processing and meet the deadline by simply working faster. When the deadline is more limiting, and the time limitation cannot be overcome by acceleration, they may focus on a subset of the available information and when this doesn't work anymore they finally have to resort to the use of a different strategy.
The present study aims to extend these conclusions on deadline effects by using a dynamic task environment rather than a static one. The task requires subjects to monitor the changing fitness level of an athlete which is continuously presented to them on a computer screen by means of a graph. They can request information, which is probabilistically related to causes underlying a decline in the athlete's fitness level. Whenever the decline is caused by some physiological disturbance they should apply a treatment in order to recover the athlete's fitness level.

1.1 Time restrictions

Compared with the deadline-experiments, time, and possibly time pressure, is conceptualized differently in dynamic situations. In a static environment subjects

start immediately after the onset of a trial with problem solving activities, and the deadline defines the extent to which information processing can be complete. In dynamic situations on the other hand, the system can show a performance decline to which the decision maker should respond at some point in time. As the situation may contain a great deal of uncertainty, they have to assess the seriousness of the decline, which possibly affects their willingness to interfere with the system. In the present experiment the time horizon is manipulated by the rate of system change, i.e. the rate at which the fitness level declines, and the main question is to what extent people change their decision making strategy in order to adapt to this time restriction. Do they for example use time differently while using the same strategy, either by speeding up information processing or intervening sooner, or do they switch to a different strategy?

1.2 Strategies in dynamic tasks

With respect to the potential decision strategies, dynamic environments provide an additional possibility, such that use can be made of feedback on the effects of implemented actions (Hogarth, 1981). Consider for example a physician diagnosing a patient. The physician may decide not to take exhaustive tests in order to infer the underlying cause, but to try a treatment first, observe its effect and then decide on her next move. On applying an incorrect treatment however, the underlying disorder will continue to affect the patient's well-being and the negative consequences are increased, especially when there is a considerable delay between treatment and observation. Kleinmuntz and Thomas (1987) termed these two strategies "judgment-oriented" (first diagnosis, than action) versus "action"-oriented (immediate action, effect is deduced from the system state). Yet, even though people seem to use an action-oriented strategy in the real world quite often, it could not be shown in a laboratory situation, even in situations where this strategy would have been most efficient (Kleinmuntz, 1985; Kleinmuntz & Thomas, 1987).
However, of main concern to the present study is that an extra dimension, time, has to be considered, if decision making behaviour is investigated in dynamic situations; when do people want information or when do they apply treatments and how much use is made of the feedback provided by the environment.

1.3 Information search and information integration

A decision making process can quite naturally be divided into two subprocesses: information search and information integration. In addition, dynamic environments also require the application of a treatment, followed by the observation of its effect on the state of the system. A central question of the present study is whether changes in time horizon affect information search and information integration differentially. Specifically, how do people deal with reduced time horizons in terms of information search and information integration? At a macro

level the relation between number of information requests and number of actions defines a "judgment" versus an "action" strategy. The difference between these strategies can be operationalised by the ratio of information requests and actions. A decreasing ratio assumes a switch from a judgment-oriented to an action-oriented strategy.
In the present study subjects are required to make decisions on a changing system (an athlete). They can request information in order to diagnose the underlying disorder, and apply treatments that may recover the system. The information is probabilistically related to the underlying causes of system decline. To date, Bayes' theorem has been mostly used to explore probabilistic reasoning, distinguishing between the prior odds or base rate information and the likelihood ratio, [P(D/H)/(D/-H)], which indicates the diagnosticity of the information. A vast number of studies has shown that people tend to ignore base-rates (Kahneman & Tversky, 1973; Lyon & Slovic, 1976). However, as noted by Medin and Edelson (1988) base-rate information is mostly derived by experience and it has been shown that when frequency information has been acquired through experience, judgments can match the normative (Baysian) outcome (Gigerenzer, Hell & Blank, 1988). Furthermore, research has indicated that subjects ignore the false alarm rate [P(D/-H)]. However, if subjects are provided with all information they do show a qualitative understanding of the diagnostic value of information (Beyth-Marom & Fischhoff, 1983). In order to enable subjects to deal with probabilistic information we gave them a training before the actual experiment started, in which they could learn the relation between symptoms and underlying causes up to a criterion level. In this training session, we provided them with both hit- and false alarm rates and they could also acquire frequency information by experience.

To summarize: The present experiment investigates the effect of time horizon on information search and information integration processes in a dynamic task environment. At a macro-level two decision strategies can be distinguished: a judgment-oriented and an action-oriented strategy. At a micro-level we will investigate what information is requested in the various time conditions, the accuracy of the diagnoses and the use of time.

2 METHOD

2.1 Subjects

Twenty students from the University of Utrecht participated in the experiment. The experiment lasted about four hours and the subjects were paid according to their performance (with a minimum of Dfl. 20).

2.2 The experimental task

Subjects were required to imagine that they were the personal attendant of an athlete who was running a race. The fitness level continuously changed over time, and is presented to the subjects on a computer screen by means of a graph (see Fig. 1). This information was constantly available to the subjects. The fitness level of the athlete could vary between 100 (optimal fitness level) and 0 (the athlete has collapsed).

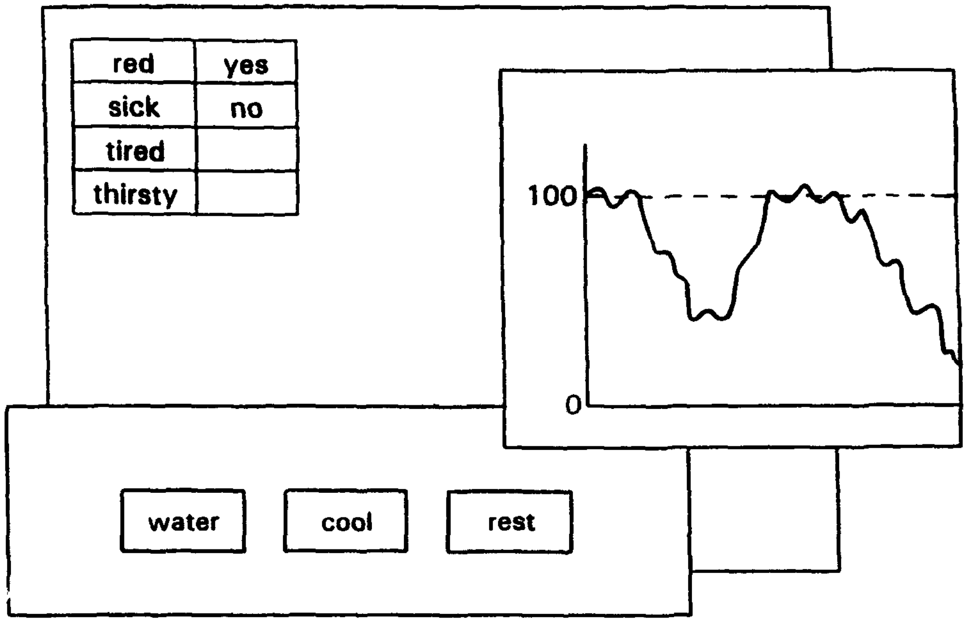

Fig. 1 Example of a computer screen, showing the athlete's fitness level in one of its windows.

At several points in time the fitness level could start to decline, which could be due to four causes with the following a priori probabilities:

1 a temperature problem: $p=0.1$
2 a circulation problem: $p=0.1$
3 a metabolism problem: $p=0.3$
4 a false alarm: $p=0.5$

A false alarm means that the fitness level of the athlete declines without any physiological cause, and as a result it will recover spontaneously after some time (at a mean fitness level of 47.9, $s=11.4$). When the decline of the athlete's fitness level was caused by either a temperature, a circulation or a metabolism problem, the fitness level would decline until a fitness level of 0, provided nothing was done by the subject.

A decline was always prompted by a change in one parameter, multiple causes were excluded. Furthermore, the decline evolved linearly [with the addition of

some random noise (mean=0, s=6.5), in order to make the task more interesting to the subjects]. The graph therefore provided information on the onset of a possible disturbance (the fitness level starts to decline) and over time subjects would learn whether the decline was merely a false alarm (the athlete's fitness level will spontaneously recover) or caused by a physiological disturbance.
Each cause may produce some symptoms in the athlete and this information could be requested by the subjects in order to determine the specific cause underlying the fitness decline. The information requests were served by mouse clicks and the response was either a "yes" (the athlete has the symptom) or "no" (the athlete does not have the symptom). The symptoms that could be requested were: red, feeling sick, tired, and thirsty. The probabilities of the occurrence of a symptom, given a particular cause are as follows (the probability of the symptom, given other causes is put in brackets):

	temperature		circulation		metabolism		no problem	
red colour	0.9	(0.2)	0.1	(0.3)	0.2	(0.3)	0.2	(0.3)
feeling sick	0.2	(0.3)	0.8	(0.2)	0.5	(0.2)	0.1	(0.5)
tired	0.3	(0.5)	0.4	(0.5)	0.6	(0.5)	0.5	(0.5)
thirsty	0.3	(0.4)	0.2	(0.4)	0.8	(0.3)	0.3	(0.5)

If a decline was caused by a physiological disturbance the subjects needed to apply a treatment in order to prevent the athlete from collapsing. For each problem one specific action was needed:
in case of a temperature problem: to cool
in case of a *circulation problem:* to rest
in case of a metabolism problem: to drink
If the correct treatment was applied the fitness level would be restored, which could be deduced from a change in the curve from a decreasing fitness level to an increasing one.

2.3 Procedure

The experiment was divided into two parts: a training session and the actual experiment. In the training session subjects had to learn the relations between combinations of symptoms and the most probable causes. They were given the information on a priori probabilities, on the probabilities of symptoms given the possible causes of the decline, [p(si/Hj)], and on the probabilities of the symptoms given other possible causes *on the decline*, [P(si/-Hj)]. The information on symptom/hypotheses relations were presented in eight bar-plots. Fig. 2 shows an example of such a plot for one of the symptoms (red colour). Subjects interacted with a computer program that presented them random combinations of symptoms (for example, "not red, not sick, thirsty and tired"). The subject had to

select the most probable cause given the symptoms. After each trial they were given feedback on the accuracy of their diagnosis and in case of an incorrect diagnosis they were also told which one should have been selected. After each run of 10 trials the subject was given feedback on his or her overall score of the run. The general learning criterion was three successive runs comprising two runs that were 100% correct.

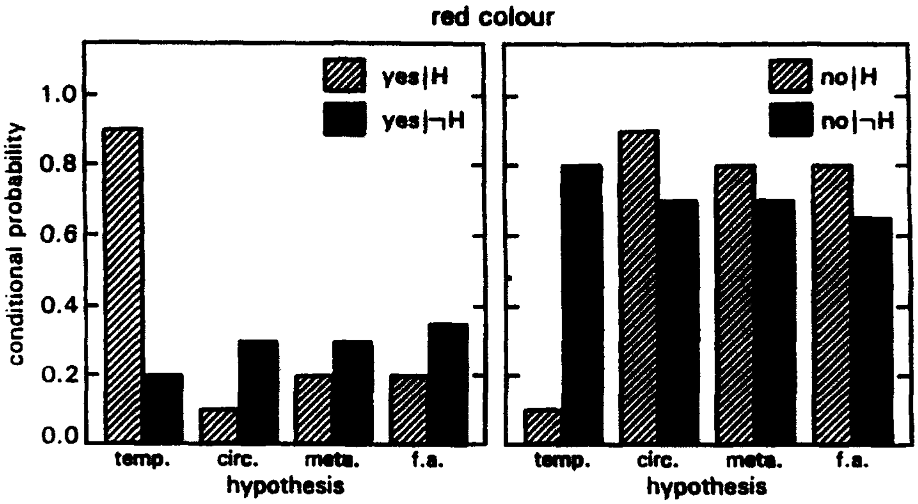

Fig. 2 Presentation of the likelihood ratios for one symptom (red colour) in the training session.

After learning the relations between symptoms and underlying causes, the subject continued with the actual experiment.

The subjects were informed on the exact probabilities and they were given practice trials for different time horizon conditions in order to get familiar with the physical task environment and to determine their decision strategy.

In order to motivate subjects to considerately trade-off information requests and risks on athlete collapses, money was deducted for information requests, wrong treatments and athlete collapses. The subjects started off with an amount of Dfl. 30.-. They paid Dfl. 0.50 for one information request, Dfl. 2.50 for the application of a wrong treatment, Dfl. 2.50 for an athlete collapse and they received Dfl. 5.- whenever they restored the athlete's fitness level correctly.

2.4 Design

Time horizon was manipulated by the slope of system decline. It was a within-subjects factor. There were three time conditions: a long time horizon (slope of -2), a moderate time horizon (slope of -1) and a short time horizon (slope of -0.5).

The subjects were presented with 15 fitness declines in each time horizon condition. Half of these declines was caused by false alarms. After a correct

treatment was applied the fitness level would increase to a value of 100 and the next trial would start.

3 RESULTS

3.1 Training

The subjects learned the relations between symptoms and underlying causes in 114 trials (s=54), and their mean score on the last trial was 99.5 (s=2.2). In can be concluded that all subjects were able to learn the relations between symptoms and underlying causes of fitness decline to a sufficient degree.

3.2 Experimental data

The results of the experiment itself are divided into two parts: information search in combination with the decision strategy that subjects used over time conditions, and information integration. All analyses were carried out over the hit-trials only (when the cause of the decline was either a metabolism, a temperature, or a circulation problem). Note that the cause of the decline could not be deduced from the graph, implying that the decision process will be the same at the beginning of each decline. However, as soon as it is observed that the fitness level spontaneously recovers, in case of a false alarm, the subjects will stop their decision making process.

Information search and decision strategy

Subjects requested the same amount of information over time conditions [$F(2,38) < 1$, see Fig. 3].
In addition to the number of information requests we also looked at the kind of information requests. We calculated how often the different types of information were requested in each time condition (see Table I). No differences were found [$\chi^2(6) = 5.37$, $p > .4$]. Thus, under the various time levels subjects requested both the same amount of information and the same kind of information.

Table I Number of times subjects requested the various symptoms in each time horizon condition.

symptom	time horizon long	moderate	short
thirsty	137	143	139
sick	55	73	59
red	69	72	66
tired	22	13	22

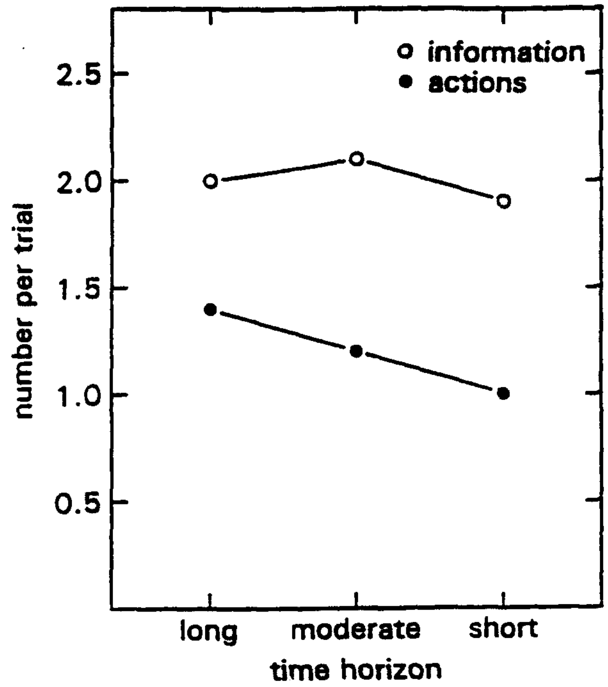

Fig. 3 Number of information requests and number of actions in each time horizon condition.

Even though the same amount of information was requested in each time condition subjects applied fewer treatments in the more restricted time horizon [$F(2,38)=3.91$, $p<.005$, see Fig. 3].
However, more athletes collapsed as the time horizon became more restricted, which may explain the decrease in treatments applied [0.14, 0.25, and 0.31 collapses respectively; $F(2,38)=13.17$, $p<.0001$ after arcsine-transformation]. Plausibly, subjects were more often too late to apply a treatment under the restricted time conditions which led to the increased number of athlete collapses.
In order to explore whether the decreased ratio "information requests/actions" was caused by a change in strategy, we also calculated the effects for the correct trials only, i.e. the trials in which the subjects recovered the athlete adequately.

Still, the same effects were found: subjects requested the same amount of information [1.9, 1.8, and 1.9 respectively, $F(2,38) < 1$], and applied fewer treatments as the time horizon decreased [1.3, 1.2, and 1.1 respectively, $F(2,38) = 3.91$, $p < .03$]. This finding suggests that different strategies were used over time horizon conditions, with a tendency from action-oriented to judgment--oriented strategies as the time horizon decreases.
This result also implies that more incorrect actions were taken with the longest time horizon, because more actions were applied in the long time horizon condition, and only one action is correct given the nature of the decline. However, these incorrect actions could clearly be corrected because fewer athletes collapsed in this time condition.

As a more direct indication for the strategy that was used by subjects we investigated the order of information requests and actions. Table II gives the various combinations that could be observed in the data; after the onset of a decline subjects could either request information or apply a treatment (action), and the same holds after an information request or after the application of a treatment. The frequency observed in each category depends on the time horizon condition [$\chi^2(10) = 29.06$, $p < .001$, see Table II]. The most salient differences over time conditions seems to be in the phase after an action is taken; in the long time-horizon condition an action is most often followed by an action (64%) whereas in the moderate and short time conditions an action is most often followed by an information request (61% and 63% respectively). This result suggests that the reaction to feedback, informing subjects that the treatment was incorrect, is dependent on the time horizon.

Table II Number of times an event was followed by either an information request or an action in each time horizon condition.

	time horizon		
	long	moderate	short
onset - info.	138	142	148
onset - action	8	7	3
info. - info.	132	140	124
info. - action	156	154	140
action - info.	21	30	15
action - action	37	19	9

The time allowed for information requests and actions in dynamic situations is significantly determined by the moment at which the subjects start their decision making process after the onset of a decline. The time that the subject waited before requesting information was calculated by the average time between onset of a decline and the moment at which the first information request was made.

When the absolute times are considered it appears that subject spent less time on "waiting" over time conditions [F(2,38)=128.81), p<.0001, see Table III]. However, relative to the total amount of time that is available in each condition these times remain constant [F(2,38)<1]. This means that subjects waited until a fixed fitness level of the athlete before they requested information.

Table III Absolute and relative times before subjects started to interfere with the athlete (request information or apply treatment).

	time horizon		
	long	moderate	short
absolute time (s)	98	50	26
relative time (absolute/total)	0.49	0.51	0.52

Information integration

The accuracy of information integration can be inferred by relating the probability of the chosen treatment to the treatment with the highest probability (given the requested information). The treatment is the behavioral response that is registered in the experiment and it is assumed that the chosen treatment reflects the presumed cause for the decline (there is only one treatment correct for each underlying cause). Accuracy is defined as follows:

$$\text{accuracy} = P\left(\frac{\text{optimal option}}{\text{requested information}}\right) - P\left(\frac{\text{chosen option}}{\text{requested information}}\right).$$

The distance between the chosen treatment and the best treatment significantly changes over time levels [F(2,38)=4.44, p<0.02; see Table IV]. By using contrasts it appeared that there is only a significant difference between the long time horizon condition and the moderate time horizon condition [F(1,19)=8.26; p<.01] and not between the moderate time horizon condition and the short time horizon condition [F(1,19)=1.79, p>.1]. Diagnoses are therefore worse when subjects have ample time to make their decision.

The time spent on integration of information can be inferred from the time difference between the last information request and the application of a treatment. On considering absolute times, subjects are faster at integrating the information as the available time is reduced [F(2,38)=15.33, p<.0001, see Table IV], suggesting an increased tempo when time horizons decrease.

Table IV Accuracy of the diagnoses and mean diagnosis time (time between last information request and the application of a treatment) in each time horizon condition.

	time horizon		
	long	moderate	short
distance optimal-chosen diagnosis	0.18	0.11	0.14
diagnosis time (s)	15.5	10.1	6.7

4 DISCUSSION

The aim of the present experiment was to investigate how time horizon would affect information search and information integration in a dynamic task.
As far as the search for information is concerned, it was found that the same amount and the same kind of information was requested over time conditions. This finding elaborates previous findings (Kerstholt, in press). Rather than requesting information on the underlying cause directly, as in our previous experiments, subjects could request information that would only increase their confidence in one of the underlying causes. But even though the present task allowed for the possibility to accept a hypothesis at lower probability levels when less time was available, subjects did not choose this option to overcome a time limitation.
As the time horizon became more restricted, subjects applied fewer treatments, suggesting a switch towards a different decision strategy. The main effect of time horizon on the decision strategy was observed in the feedback phase; after noticing that a wrong treatment was given, subjects just tried another treatment in the long time horizon condition, but requested more information in the restricted time conditions. Presumably, subjects wanted to be more certain of their diagnosis in the restricted time-condition before applying a treatment, whereas they could take more risks with the longest time horizon. Contrary to the prediction, less use is therefore made of the dynamic characteristics of the task in the restricted time conditions. Even though the effect of an action could immediately be deduced from the evolving fitness level, subjects chose to request additional information.
Note however, that this finding only refers to the responses after subjects had been informed that they had applied an incorrect treatment (deduced by the continuing decline of the athlete's fitness level). The first reaction to a decline in fitness level was to request information, which was then followed by an action. This judgment-oriented strategy agrees with previous findings (Kerstholt, in press; Thomas & Kleinmuntz, 1987). One aspect of the task possibly affecting

the choice of a judgment-oriented versus action-oriented strategy, however, are the specific costs of information versus treatments. In the present experiment the application of a wrong treatment was five times the costs of an information request. It is predicted that if actions are less expensive than the information, subjects will switch to an action-oriented strategy.

The accuracy of the diagnoses given the actual system state was lower in the long time condition; more incorrect actions were applied. As discussed in the previous paragraph subjects used a more action-oriented strategy in this condition, which explains the less accurate diagnoses. The same result was also found, however, for the accuracy of information integration given the requested information; in the long time horizon condition the worst diagnoses were made. A possible explanation for this finding is that subjects experienced a situation of mental underload; the system only slowly changed which may have reduced the subjects' motivation to spend much effort into the task.

The most robust effect of decreased time horizons was found in the acceleration of information processing. Even though better diagnoses were made, subjects were faster in the more restricted time horizon conditions. This result is in agreement with previous findings on speed-up effects in deadline-experiments (Maule & Mackie, 1990; Payne, Bettman & Johnson, 1988). These results suggest that subjects try to overcome moderate levels of time constraints by not only thinking faster but also thinking smarter.

Subjects waited relatively the same amount of time after the onset of a fitness decline before they started to interfere with the system. More specifically, they waited until a fitness level of about 50, before they started to request information. Because more athletes collapsed in the more restricted time horizon conditions, it can be deduced that subjects started too late with their diagnosis process in these conditions. It might be that the acceptance of risks relates to the concept of time in relation to seriousness of fitness level. In an overview on research in three different domains on the way in which people perceive time, Björkman (1984) concludes that people largely focus on the present time, and are therefore more willing to take risks when consequences are further ahead. Note, however, that in the present experiment there was a relatively high probability of false alarms, i.e. a fitness decline not caused by a physiological disturbance, on which subjects would be informed after some time (when the fitness level would spontaneously recover). One possible explanation for the waiting-span is this a priori probability of hits/false alarms, which remained constant across time conditions. Future research has to indicate whether the moment of interference relates to the false alarm/hit rate.

To conclude, subjects did not change their timing in order to meet the task requirements in the restricted time horizon conditions, i.e. they waited until a fixed fitness level before requesting information, resulting in an increased number of athlete collapses. The most plausible explanation for this result seems

to be the probabilities of hits/false alarms. Furthermore, specific characteristics of the task may have affected the findings such as the costs of information and treatments, the availability of immediate feedback after the application of a treatment and the chosen time horizons. Future research will reveal the effects of these variables on decision making behaviour in dynamic situations.

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The effect of the time restrictions on information search and information integration in a dynamic task environment

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15. ABSTRACT (MAXIMUM 200 WORDS, 1044 BYTE)

To date, research has mainly used deadlines in static task environments to investigate the effects of time pressure on decision making behaviour. A dynamic environment, on the other hand, changes over time and time pressure may result when time is not used efficiently and negative consequences are rapidly increasing.
An experiment was carried out to investigate the effects of time horizon on decision making behaviour in a dynamic task environment. Subjects were required to monitor the fitness level of a running athlete, depicted graphically on a computer screen, and to apply a proper treatment whenever necessary. Information could be requested on symptoms, which were probabilistically related to underlying causes. The time horizon was manipulated by the speed at which the athlete's fitness level changed over time.
Restrictions in time horizon did not affect the amount and type of information that was requested, and the diagnoses became even better. Nevertheless, more athletes collapsed in the more restricted time horizon conditions. In the short time horizon conditions subjects furthermore employed a more cautious decision strategy. As far as the use of time was concerned it was found that information processing was speeded up, but subjects waited relatively the same amount of time before they started to intervene with the system.

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